Art. II.—*The Maintenance of Energy.*

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In course of a conversation with Mr. J. P. Thomson over twelve months ago, I mentioned to him that I held different views respecting the nature and causes of volcanic action, and of elevation and subsidence, to those usually accepted. Mr. Thomson was then good enough to ask me to contribute a paper to your Society setting forth these views. I have since been collecting materials. The theories I hold depend almost entirely on the action of a force which I venture to think has not received the attention it merits. I propose to devote this short paper chiefly to the consideration of the form of energy in question.

It has frequently been said by geologists that discussions regarding the origin of the earth are outside the province of their science. It is difficult to conceive on what grounds this statement rests. How are we to understand the laws which regulate volcanic action, elevation and subsidence, earthquakes, and other kindred phenomena unless we know how the solid earth was formed? Everything must depend on this.

One of the most noteworthy facts brought before students of astronomy and geology is the extraordinary discrepancy in the evidence presented by the two sciences respecting the age of our planet. Geologists are almost unanimously of opinion that at least something like one hundred millions of years must have elapsed since the first appearance of life on our globe. Astronomers would limit the age of the sun himself from beginning to end, to some such period as thirty millions of years. Whatever opinions may be formed regarding the theories which follow, it must be borne in mind that those now received are admittedly incompetent to explain facts. While the geologist can apparently furnish satisfactory reasons within the limits of his science, his conclusions clash with the requirements of physical astronomy, and *vice versa.*

The nebula theory of Kant and Laplace is, that all the materials out of which the bodies of our solar system were formed were in the beginning of things resolved in their original elements, and filled all the space of the universe in which these bodies now move. This nebulous mass was in an intensely heated gaseous condition. It condensed towards the centre, and in doing so threw off successive rings which on further disruption and condensation assumed the form of planets. The sun himself is now supposed by most astromers to be almost altogether gaseous to the centre (Young.)*

One of the most interesting questions of cosmical physics is how the sun has been radiating heat into space for millions of years without any apparent diminution of the supply. How is this continued outpouring of heat maintained? If we calculate at what rate the temperature of the sun would be annually lowered by the radiation from its surface, we find it to be 2⅓° F. per annum, supposing its specific heat to be that of water, and from 5° to 10° F. per annum, if we suppose it to be the same as most of the substances which compose our globe (Young). It would entirely cool off in a few thousands of years after its formation if it had no other source of heat than that shown by its temperature. It has been attempted to explain the source of its maintenance of heat in two ways. The first is known as the meteoric theory and it is—that the heat of the sun is kept up by the impact of meteors upon his surface. It is considered that though the sun may at some past time have received a large supply of heat in this way, the quantity of meteoric matter now falling is totally inadequate to keep up the supply. The second is the contraction theory which appears to be accepted by most astronomers. As the sun's globe cools off it must contract, and the heat generated by this contraction will suffice to make up the entire loss. Knowing the amount of energy which the sun annually radiates in the form of heat, it has been calculated from the mechanical equivalent of the heat thus radiated, by what amount it must contract to make it up. With the present

* The Sun. International Scientific Series.

magnitude of the sun it has been found that the diameter must contract about 220 feet a year to produce all the heat which it radiates. This rate of contraction diminishes as the sun grows smaller, at such a rate that in five millions of years it will be reduced to one half its present volume. At the present rate of radiation the sun will be as dense as the earth in about twelve millions of years. As to the past, it has been calculated that the heat evolved by contraction from an infinite size or by the falling together of all the parts of the sun from an infinite distance would only have been sufficient to last eighteen millions of years at the present rate of radiation. This is the extreme limit of the heat the sun could acquire. Professor Young says if this hypothesis is true, as it probably is in the main, we are inexorably shut up to the conclusion that the total life of the solar system from its birth to its death is included in some such period as thirty millions of years. No reasonable allowances for the fall of meteoric matter based on what we are now able to observe, or for the development of heat by liquefaction, solidification, and chemical combination of dissociated vapours could raise it to sixty millions.

According to Geikie the argument from geological evidence is strongly in favour of an interval of probably not much less than one hundred millions of years since the earliest forms of life appeared upon the earth, and the oldest stratified rocks began to be laid down.

Let us start on the assumption that the space in which the members of the solar system now move was filled with the matter now forming them. First, as to the constitution of this nebula. We may either assume it to have been one element out of which all substances have been in some way evolved, or we may assume it to have been a mixture of various substances which are themselves elements. Since we have absolutely no proof that the substances known to us as elements can be resolved into a single element, we are hardly justified in making the first assumption. Let us then suppose the nebula to have been composed of different elementary substances, which may have been present in various quantities, and that these substances were uniformly distributed throughout it from centre to surface. Second, as to its condition, we may suppose it to have been in a more or less heated condition or at the absolute zero of temperature. We have already seen that on the assumption that it was in a heated condition we cannot account for such a maintenance of energy as would satisfy geological requirements, let us assume that the whole was at the absolute zero of temperature. We regard this nebula then as having at first a uniform density throughout, a uniform composition throughout, and at the absolute zero of temperature, *i.e.*, with an entire absence of molecular motion. Now its components cannot have been in a gaseous state, since a gas, to exist as such, requires molecular motion, neither can they have been liquid. They must therefore have been in the solid state of matter. Let us now conceive the whole volume condensing, or growing smaller, by gravitation to the centre of gravity of the whole. It is evident that the matter nearest to the centre of gravity would eventually be the matter at the centre of the sun. Now the heat generated by the collision of a falling body varies as the square of the velocity of that body at the point of impact. But the matter nearest to the centre of gravity would have the least distance to fall, and the force of gravity would there be least. Its velocity therefore at point of impact would be least, so that less heat would be generated by the falling together of any given quantity of matter near to the centre, than would be generated by the falling together of an equal quantity situated at a further distance from it. A body therefore formed in this way would be relatively cold at the centre, and the temperature would increase in a definite ratio towards the surface. The heat generated would not wholly be lost by radiation into space part of it would, by conduction, heat the cooler matter nearer to the centre and would perform work.

On this view of its formation we may then conclude, that the sun was never wholly in a gaseous or plastic state, that its centre at first was cool and solid, that its formation was attended by the gradual development of heat, that as heat was generated the more volatile substances became vapours, that on approaching the surface the heat was much more than sufficient to turn all substances into a gaseous state. As the cooler matter in the interior became heated by conduction, the various materials would on arriving at their successive critical temperatures turn to vapour. In dealing with the question of the maintenance of the sun's energy we have to consider the action of two forces, namely, the contraction of the matter in a gaseous state on its surface, and the expansion from excess of heat of the materials nearer the centre. The question of the duration of the sun's energy is therefore an extremely complicated one. Any given substance would on arriving at its critical temperature turn to vapour, this vapour would exercise an explosive force on the materials between it and the surface. There are between sixty and seventy elements, and the critical temperature of each one differs. The matter about the surface would be upheaved or disturbed an indefinite number of times. This would continually generate an enormous amount of heat. If this is the case it is an almost hopeless task to compute the duration of the sun's energy. It would depend partly on the proportion in which the various elementary substances were present, and partly on the rate of conductivity of the solid materials deep down from the centre and the resistance offered. Until the greatest possible amount of heat had passed by conduction to the centre, and the vapours formed had performed work, we would not be justified in regarding the sun as a body actually cooling. He is continually parting with the energies, and their expenditure maintains the heat. What is known of the physical constitution of the sun's surface would appear to support this view. There would be a continual storing up of energy, the force of which would be dependent on the amount of resistance to be overcome. The sunspots and faculæ with their periodicity might be caused by the gathering up of the internal forces during seasons, followed by outbursts relieving the internal energies. The eruptive or metallic prominences whose spectra show the lines of sodium, magnesium, barium, iron and other metals, occasionally rise to a height of over 200,000 miles above the chromosphere. The velocity of the motions of these prominences sometimes reaches 200 miles a second. This points to the existence of enormous eruptive forces in the sun's interior. We might regard the sunspots, faculæ, and eruptive prominences as analgous to terrestrial volcanoes, the difference between the solar and terrestrial forces being due to the greater intensity of the former, and to the sun's surface being in an intensely heated gaseous condition.

So far we have dealt with the sun himself and have not considered the mode of formation of the planets. As the nebula condensed heat would be generated by friction between the solid particles themselves while falling, and the more volatile substances would become vapourised, the less easily melted parts would be enveloped in a gaseous atmosphere, and the light particles would not fall so quickly as the heavier ones. This would occasion a decrease of density at the outer parts of the nebula. Now the formation of the planets can be explained in somewhat the same way as before. The sum total of the rotary motion now existing in the planetary system must have been in the nebula, and as the volume contracted by gravitation towards the centre, its velocity of rotation would constantly increase, so that at last the centrifugal force due to rotation would balance the attractive force of gravity.

The orbits of all the larger planets are approximately in the plane of the ecliptic, and a planet may be regarded as having been formed from masses of the nebula thrown off by centrifugal agencies. On assuming a separate existence from the parent nebula, we must consider its development to have been analagous to that of the sun. There would be a continual falling together of the particles composing it to the centre of gravity of the mass. This condensation would be accompanied by the generation of heat through friction between the particles, and a further differentiation of matter would be occasioned. So that the matter composing satellites would be of less density. The forces at work were exactly the same as those in the sun, but different in degree. We may draw then the following conclusions concerning the earth; that it was never wholly in a plastic or a gaseous state, that its centre was relatively cool and solid and that the temperature gradually increased towards the surface; that through loss of heat by radiation into space a solid crust was formed, and that the cooler matter in the interior became gradually heated through conduction, and the more volatile constituents continually assumed a liquid and vapourous condition. Now these vapours would be obliged to find some outlet. The cooled crust at the surface would crack just in the same way that a boiler full of water, subjected to intense heat and without a safety valve, would crack. Now terrestrial volcanoes are built up along lines of fissure in the earth's crust and almost all the active ones are situated on rising areas. Nearly all can be shown to be thrown up along three well-marked lands or great fissures and the branches proceeding from them. They traverse the surface of the globe in sinuous lines with a general north and south direction and the branches often appear to form connections between the great bands. The first and most important of these bands is nearly 10,000 miles in length. It stretches from near the Arctic Circle at Behring's Straits, to the Antarctic Circle at South Victoria. The volcanoes in Kamschatka, in the Aleutian Islands, in the Kuriles, and in the Islands of Japan are on this band. The second band starts from near the last in the neighbourhood of Behring's Straits, and stretches along the western coast of the American continent. It is about 8000 miles in length. The third forms a ridge running through the Atlantic Ocean, and divides it longitudinally into two basins. This last chain appears to be verging on extinction, as the number of extinct volcanoes is greater than the active ones, and partial submergence has taken place.

With regard to volcanic phenomena, the two great factors which have to be accounted for are the presence of highly heated rock masses within the earth's crust, and the existence of various vapours and gases in a state of most intimate mechanical but not chemical union with them. (See *Judd on Volcanoes*, page 360.) The active phenomena of volcanoes must be referred to the presence of these gases and vapours.

It may be remarked that the theory advanced explains the linear arrangement of volcanoes, the cause of the intense heat, and the presence of vapours and gases in the earth's interior, without assuming it to be other than a rigid mass.

In investigating the changes and movements which the earth's crust has been subjected to throughout geological time, we must consider the action of two forces. Loss of heat through radiation into space is continually going on from the external portions of the globe. This is accompanied by contraction. On the other hand, access of heat by the materials far down in the interior would give rise to an expanding or explosive force. The extent of this force would depend on the amount of volatile materials among the substances in the earth's interior, the rate of conduction of heat to them, and the resistance to be overcome. In early geological times subterranean action, or rather its effects, may have been less because the crust was not so thick, and the resistance to be overcome would have been less. This may account for the enormous times occupied during the deposition of some of the older formations and the greater uniformity observed among their rocks. If the resistance to be overcome was great the forces would accumulate, but they must at some period find an outlet. The phenomena in connection with elevation and subsidence, and the formation of mountain chains, may, to a great extent, be explained in this manner. Through extended observations of the rocks in different formations and localities, it has been ascertained by geologists that the subterranean forces are in a state of continual flux over the surface of the globe. They make themselves felt in an area, attain a maximum, and then decline. As regards the formation of mountain chains—The first stage appears to be the opening of a number of fissures running along a line near to that at which, in a long subsequent period, the elevation of the mountain masses takes place. The second stage consists in a general sinking of the surface along the line of weakness and the deposition of great quantities of sedimentary materials. The third consists of a series of movements affecting the parts of the earth's crust on either side of the line of weakness. By these movements a series of tangential strains are produced, which result in the violent up-crushing, folding, and crumpling of the sedimentary materials deposited. Fissures again appear on either side of the original line of weakness from which volcanic outbursts take place. Mountain chains may be regarded as cicatrised wounds in the earth's crust. The subterranean energies after probably accumulating for ages, appear to first find an outlet. Enormous quantities of gases, vapours, and molten rocks are brought to the surface. The forces at last become exhausted and subsidence takes place. The original fissures become closed up and covered with sedimentary deposits of immense thickness. The line of weakness becomes stronger than the adjacent portions of the crust. After long ages the accumulated forces again make themselves felt, elevation takes the place of subsidence, new fissures are formed in the weakest places, the lateral forces come into play, and the sediments overlying the original fissure are upheaved. If we admit the existence of this internal energy, we may have these processes repeated an indefinite number of times over any portion of the earth's crust.

In this paper I do not propose to enter more fully into the subject, but hope, at some future time, to have an opportunity of exhaustively reviewing that branch of dynamical geology which treats of it. I think that by means of this force, a more or less complete explanation of the majority of the most interesting problems presented can be given, especially as regards the causes of the movements of portions of the earth's crust in the carboniferous age, and the origin of earthquakes, earth-tremors, and earth-oscillations.

It must be remembered that the nebula theory of Kant and Laplace was given to the world before the discovery of the mechanical equivalent of heat. The whole question of the maintenance of the sun's energy would seem to depend on whether the original nebula was in a heated condition or not. Now, the conception of Kant was that the entire universe was filled with this nebulous matter, and that all the heavenly bodies have been evolved from it. If space had been altogether filled with this intensely heated nebulous matter, it is difficult to conceive how heat could have been lost by radiation into space. We know that heat is molecular motion, and we know that molecular motion is caused by intercepted mechanical motion. It is hard to see what *a priori* right we have to assume the presence of intense molecular motion in the original nebula without accounting for it. If we suppose infinite space to have contained an infinite number of almost infinitely small particles at equal distances apart, holding potentially, by virtue of their diffusion, all the energies subsequently evolved, we may assume the entire absence of molecular motion. In its absence the particles must have been in the solid condition of matter. Let them aggregate to centres of gravity, those nearest a centre must at point of impact have acquired less velocity than those falling from a further distance, consequently less heat would be generated, and a body formed thus would be constituted as previously indicated. As to the ultimate origin of these things, science can offer no explanation, but points to the existence of an Infinite and Eternal Power.